Measuring R_K at high q^2

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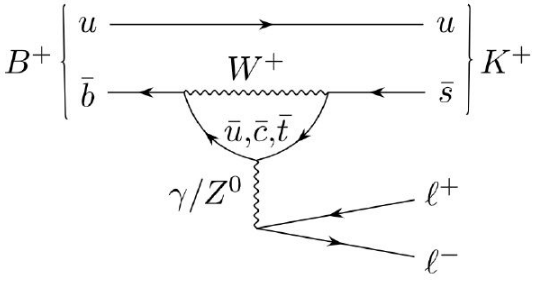
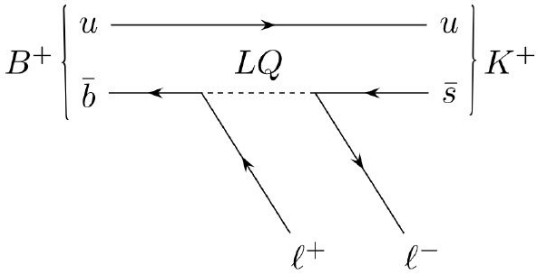
Rare *B* meson decays

- Decay of ***B*** meson into a **kaon** and **two leptons** heavily suppressed in the SM
- New physics contributions may alter characteristics of final state particles
- Lepton flavour universality predicts **BF($B^+ \to K^+\mu^+\mu^-$) = BF($B^+ \to K^+e^+e^-$)** with negligible theory uncertainty
- Indirectly search for new physics by measuring $\boldsymbol{R_K}$
- Any significant deviation from unity would hint at new physics

Standard Model



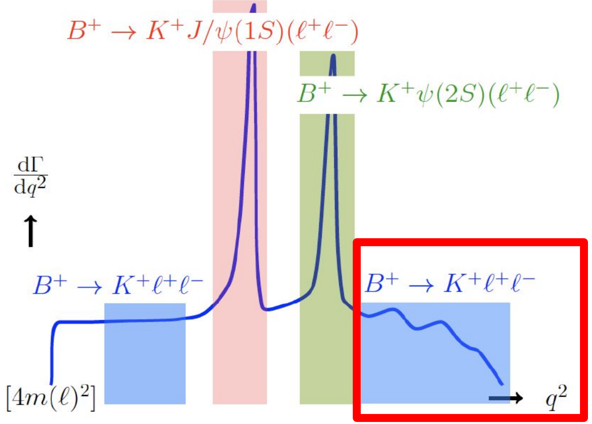
New Physics Leptoquark

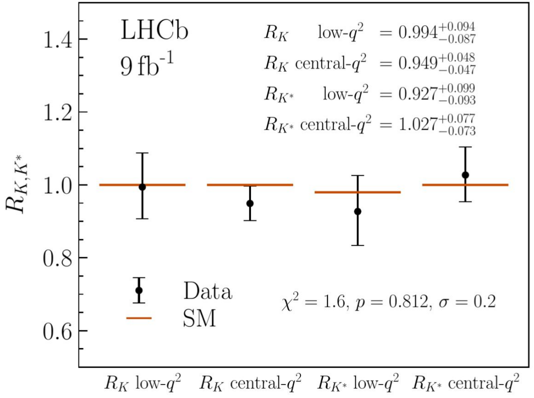


$$R_K = \frac{\int_{q^2_{min}}^{q^2_{max}} \frac{d\mathcal{B}(B^+ \to K^+\mu^+\mu^-)}{dq^2} dq^2}{\int_{q^2_{min}}^{q^2_{max}} \frac{d\mathcal{B}(B^+ \to K^+e^+e^-)}{dq^2} dq^2} = 1$$

Why high q^2?

- Dilepton invariant mass squared (q^2) spectrum of $B \to Kll$ includes resonant peaks → no sensitivity to NP
- R_K in the resonant free region **$1.1 < q^2 < 6.0$ GeV^2/c^4** has previously been measured by LHCb and found to be consistent with SM expectation
- Currently no competitive measurement in the **high q^2** region above the charmonium resonances





[Phys. Rev. D 108, 032002]

LHCb experiment

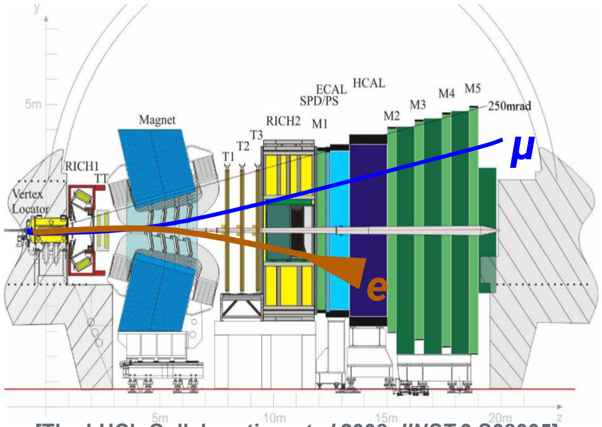
Two final states differ by presence of electrons or muons in final state

Muons

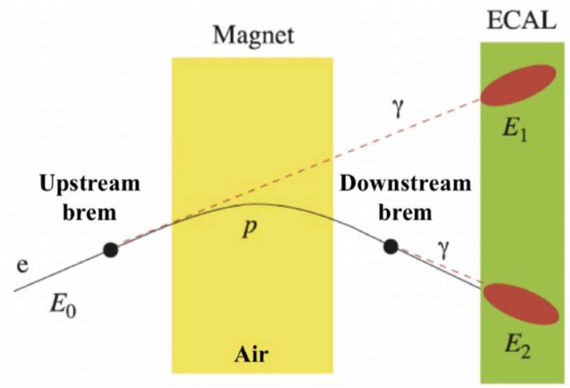
- ❑ Minimum ionising → penetrate through to muon chambers
- ❑ Good trigger efficiency & resolution

Electrons

- ❑ Produce EM shower in ECAL
- ❑ Radiate bremsstrahlung radiation
    - ❑ Poor momentum resolution
    - ❑ Poor trigger efficiency

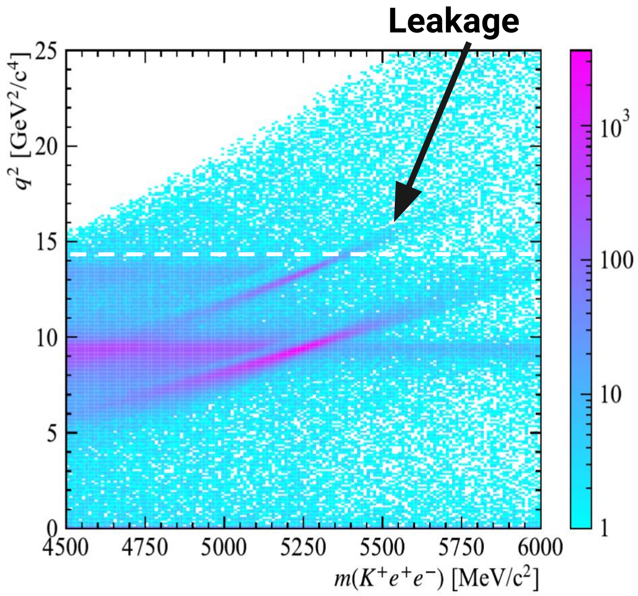


[The LHCb Collaboration *et al* 2008 *JINST* 3 S08005]



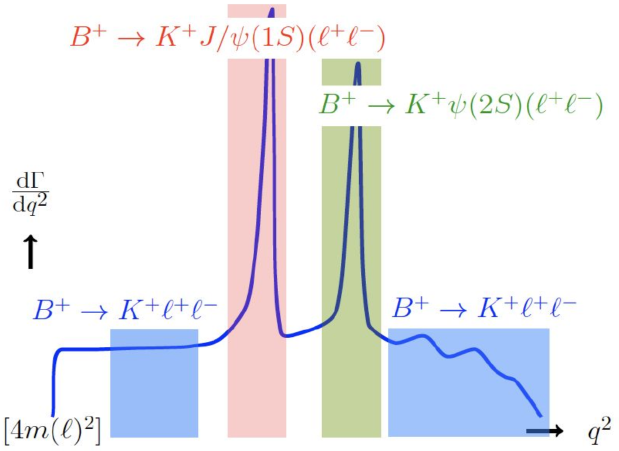
$B \to K^+ \Psi(2S)(\to e^+e^-)$ background

- Incorrect bremsstrahlung recovery leads $B^+ \to K^+ \Psi(2S)(\to e^+e^-)$ to leak upwards in q^2
- A cut on $q^2_{no\ brem}$ is incredibly efficient at removing **$\Psi(2S)$** leakage backgrounds
- Signal efficiency reduced by 50% relative to an equivalent cut on **q^2**
    - **Toy studies show that increased signal purity outweighs reduced signal yield**



Measuring R_K as a double ratio

- Naive extraction of R_K would use a single ratio
- Efficiency related systematic between electrons and muons do not cancel
- R_K far more robust against efficiency related systematics when measured as a double ratio



$$R_K = \frac{N(K^+\mu^+\mu^-)}{N(K^+e^+e^-)} = \frac{n(K^+\mu^+\mu^-)}{\epsilon(K^+\mu^+\mu^-)} \cdot \frac{\epsilon(K^+e^+e^-)}{n(K^+e^+e^-)}$$

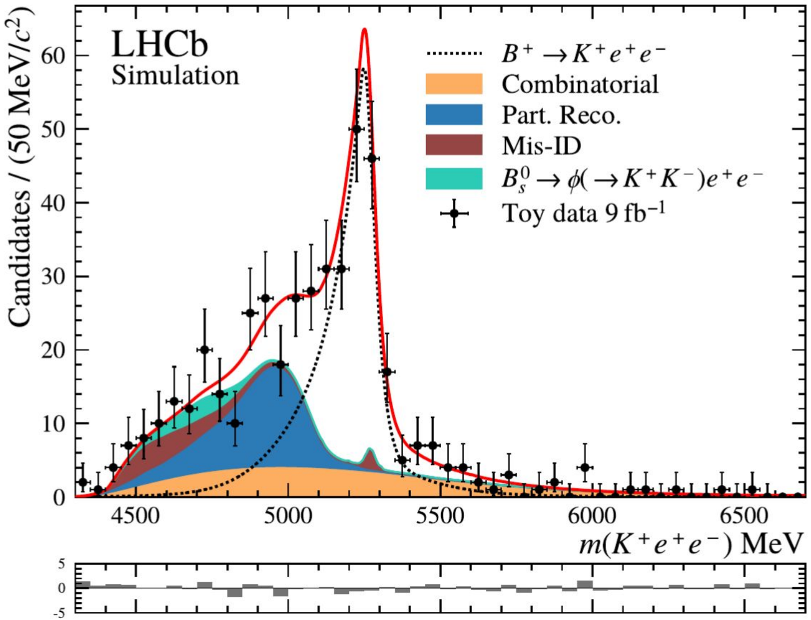
← **Single ratio**

Double ratio →

$$R_K = \frac{N(K^+\mu^+\mu^-)}{\epsilon(K^+\mu^+\mu^-)} \cdot \frac{\epsilon(K^+e^+e^-)}{N(K^+e^+e^-)} \cdot \frac{\epsilon(K^+J/\psi(\mu^+\mu^-))}{N(K^+J/\psi(\mu^+\mu^-))} \cdot \frac{N(K^+J/\psi(e^+e^-))}{\epsilon(K^+J/\psi(e^+e^-))}$$

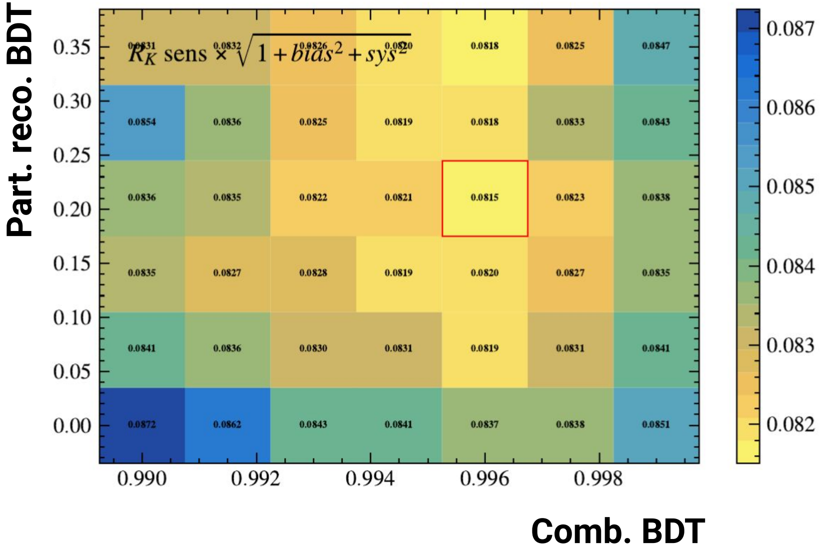
Extracting $B \to Kee$ yield & toys

- Precision of R_K is limited by observed yield of $B^+ \to K^+ e^+ e^-$ decays
- Yield is extracted by fit to invariant mass $m(K^+e^+e^-)$
- Three main backgrounds contribute to the fit
  1. Combinatorial (random combination of three tracks)
  2. Partially reconstructed decays i.e $B \to K^*(K\pi)ee$
  3. Hadron→electron mis-ID i.e $B \to K\pi\pi$



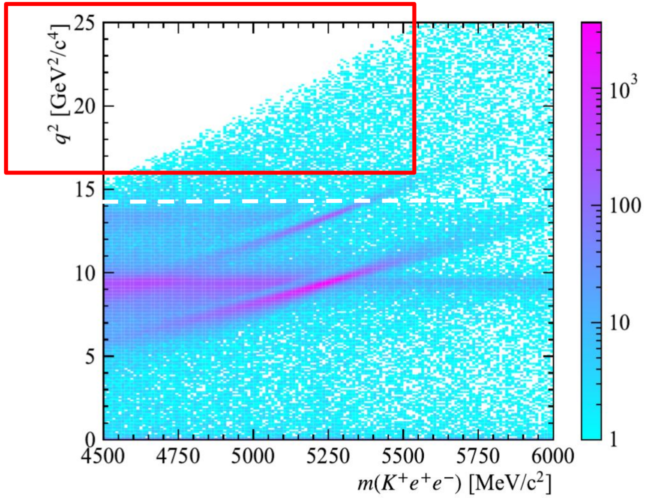
Boosted decision trees

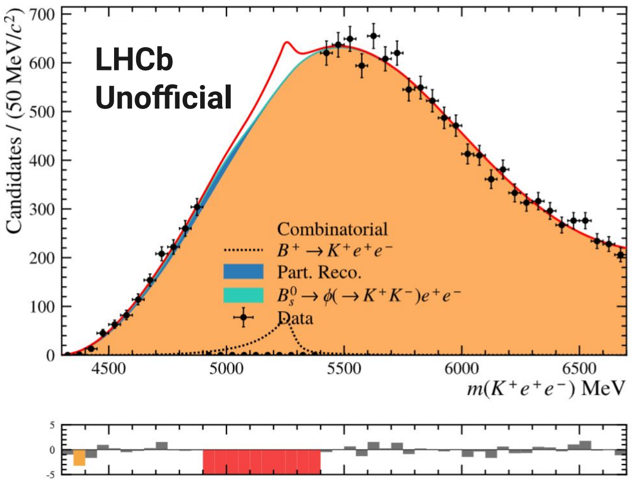
- Two largest backgrounds in $B^+ \to K^+ e^+ e^-$ channel are combinatorial and partially reconstructed events
- Train two boosted decision tree classifiers targeted to suppress each background type
- Working point of the two BDTs are optimised simultaneously in toys fits
  - Optimise statistical + systematic uncertainty on R_K



Combinatorial shape

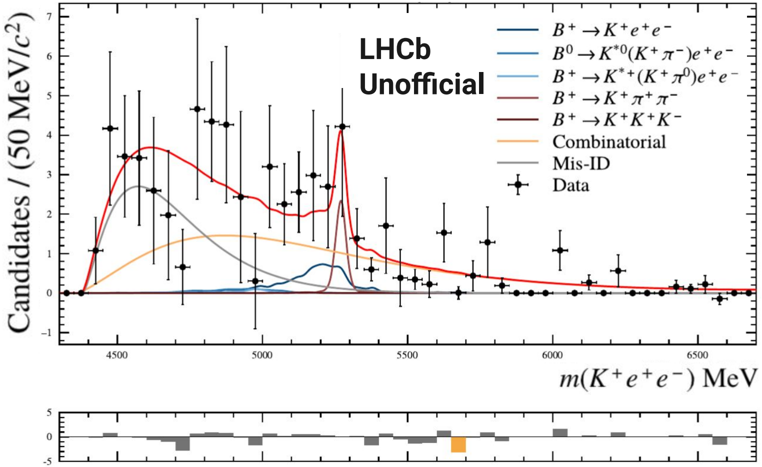
- High q^2 requirement imposes phase-space restriction on combinatorial events
  - Cannot be modelled by simple exponential
  - Use custom single-parameter model that takes into account phase-space boundary
  - Fold in resolution effects & efficiency dependence of selection cuts
- Validate model by comparing to side band data





Hadron → electron misidentified background

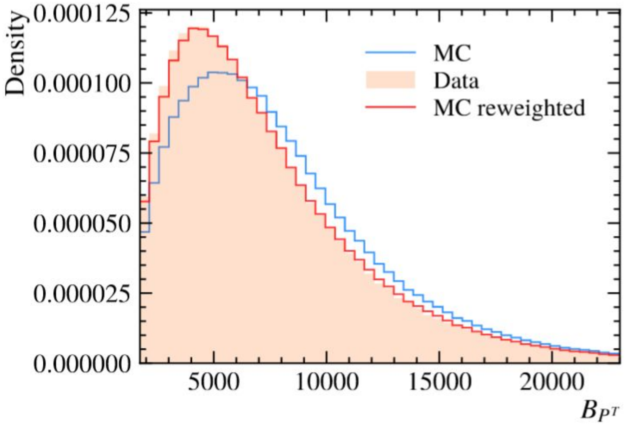
- Three sources of mis-identified backgrounds
  - $B^+ \to K^+ \pi^+ \pi^-$
  - $B^+ \to K^+ K^+ K^-$
  - **Residual mis-ID**



- Suppress by applying particle identification criteria using information from LHCb sub-detectors
- Model for surviving mis-ID events derived using data-driven method known as pass/fail [Phys. Rev. D 108, 032002]
  - Produce sample enriched in mis-ID by inverting PID criteria
  - Extrapolate inverted PID data into nominal PID region using "transfer weights"

Cross-checks using resonant channels

- Efficiencies derived from simulation may be biased due to mis-modelling
  - Double ratio helps make R_K robust against efficiency biases
  - Additionally, simulation is corrected using $B^+ \to J/\Psi\, K^+$ control data



- Check control of efficiencies by measuring $r_{J/\Psi}$ single ratio
  - Single ratio → no cancellation of efficiency biases
  - $r_{J/\Psi}$ consistent with unity → excellent control of efficiencies

$$r_{J/\psi} = \frac{\mathcal{B}(B^+ \to K^+ J/\psi(\mu^+\mu^-))}{\mathcal{B}(B^+ \to K^+ J/\psi(e^+e^-))}$$

Conclusions

- Measuring R_K at high q^2 is a further test of LFU in rare B decays
  - Using full Run 1 & Run 2 LHC data sample
- Selection strategy results in a high signal purity
- Expected statistical + systematic R_K precision of ~8%
- Analysis is currently in review
- R_K is statistically limited by sample size → Run 3 and beyond data will enhance measurement

Thank you for listening!